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ARMSTRONG LABORATORY

ULTRASHORT-PULSE LASER SYSTEM: THEORY OF OPERATION AND OPERATING PROCEDURES

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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This report describes the ultrashort-pulse laser system manufactured by Spectra-Physics, Inc., in detail so the system operator can turn on the system, bring it up to operating specifications, and fine-tune the system to give optimum pulsewidth and energy/pulse output. This report also incorporates the system turn-on procedures developed for the system license and includes greatly expanded optimizing procedures in addition to the theory of operation of each component instrument. The basic system has been configured to operate on a single 4- by 12-ft optical bench. Some diagnostic instruments are also permanently mounted on the bench.

Each system component is described in the same order as required to turn on the system and reach stabilized pulses. The theory of operation will be incorporated into this turn-on procedure along with optimizing procedures. Much of the theory of operation was copied verbatim from the instrument manuals provided by Spectra-Physics.

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ULTRASHORT-PULSE LASER SYSTEM:

THEORY OF OPERATION
AND
OPERATING PROCEDURES

INTRODUCTION

This report describes the ultrashort-pulse laser system manufactured by Spectra-Physics, Inc., in detail so the system operator can turn on the system, bring it up to operating specifications, and fine-tune the system to give optimum pulsewidth and energy/pulse output. This report also incorporates the system turn-on procedures developed for the system license and includes greatly expanded optimizing procedures in addition to the theory of operation of each component instrument. The basic system has been configured to operate on a single 4- by 12-ft optical bench. Some diagnostic instruments are also permanently mounted on the bench.

Each system component is described in the same order as required to turn on the system and reach stabilized pulses. The theory of operation will be incorporated into this turn-on procedure along with optimizing procedures. Much of the theory of operation was copied verbatim from the instrument manuals provided by Spectra-Physics. The complete system by model number is listed in the following section.

LIST OF EQUIPMENT

1. Model 3800 Nd:YAG Continuous-wave Mode-locked Laser with Model 3242 Mode-locker
2. Model 3695 Optical Pulse Compressor/Frequency Doubler
3. Model 3275 Acousto-optic Stabilizer
4. Model 3500 Ultrashort-pulse Dye Laser
5. Model CPA-2 Fiber Prism Compressor for Chirped Pulse Amplification
6. Model PDA-L3 Pulsed Dye Amplifier
7. Model GCR-3RA Pulsed Nd:YAG Laser with Regenerative Amplifier
8. Model IO-5-VIR Optical Isolator-Optics by Research Mfg.
9. Model MST412 Optical Table by Newport Mfg. Corp.

SYSTEM DESCRIPTION

A sequential instrument-by-instrument turn-on procedure is required to operate the system because each stage requires the correct output power and pulse shape of the preceding stage to operate correctly. Thus, the theory of operation and turn-on procedures will be given on the same instrument-by-instrument basis. See Fig. 1 for a block diagram of the ultrashort-pulse laser system.

Model 3800 Nd:YAG Laser System

The Model 3800 laser system consists of the Model 3800 laser head and the Model 3242 mode locker and power supply. Other accessories include the Model 3225 frequency doubler, the Model 3275 acousto-optic (a-o) stabilizer, and the Model 3695 optical pulse compressor. The laser system incorporates a neodymium:yttrium-aluminum-garnet (Nd:YAG), continuous-wave laser.

Resonator Structure

The resonator provides a stable optical cavity. The resonator structure must resist flexure, vibrations, and other mechanical distortions. Additionally, for maximum length stability, the structure must be insensitive to temperature variations. Cavity length stability is critical for optimum mode locking. The resonator structure used in this laser is a linear, three-rod, graphite composite resonator suspended from a rigid L-structure. The advantages of this resonator are its angular and length stability. The low-expansion, graphite-composite rods contribute to an overall cavity-length stability better than 0.5 $\mu/^{o}C$, and the rigid L-structure provides a solid base for mounting cavity components and accessories. To maintain precise optical alignment, two mirror mounts with a special locking feature complete the overall resonator.

Optical Cavity

This laser uses a symmetrical concave/concave optical cavity with the Nd:YAG rod located at the center. The design has several distinct advantages: (a) the largest intracavity beam diameter is located within the Nd:YAG rod, resulting in the most efficient use of the gain volume; (b) this cavity has minimal sensitivity to misalignment; and (c) computer modeling has shown that a symmetrical cavity is the least sensitive to thermal lensing, which affects the stability by the thermal load on the rod, which in turn is affected by the lamp current. This design allows the Model 3800 to be stably operated over a wide range of lamp current.

The elliptical pump chamber, which holds the krypton arc lamp and the Nd:YAG rod, incorporates several features. An extra long, large bore lamp keeps the lamp electrodes outside the pump chamber to reduce power loss as the lamp ages. The large bore works in

concert with a large ellipse to produce a high transverse electromagnetic mode (TEM_{00}) power conversion, reduce depolarization from thermal birefringence, and eliminate pump-induced astigmatism. The size and position of the aperture can be readjusted if needed to ensure excellent beam quality and optimum mode locking. Also, the optical cavity can be purged with nitrogen using an optional purge control unit to reduce the need for cleaning optical components.

Power Stabilizer

This unit incorporates a power stabilizer (Model 3275 acousto-optic stabilizer/light mode) to actively stabilize either the 1064-nm or 532-nm output. The built-in stabilizer utilizes a photodetector and feedback loop circuit to modulate the lamp current to compensate for fluctuations in optical output. The stabilizer has an effective bandwidth greater than 3 kHz, a range broad enough to reduce noise at 1064 nm to less than 1% (peak-to-peak). The stabilizer detector is mounted at the output of the compressed/doubled 532-nm-pulse output. This unit uses a wide bandwidth detector to sample the frequency-doubled output of the pulse compressor. The traveling-wave a-o modulator is placed between the Nd:YAG laser (inside the Model 3800 cover) and the pulse compressor. The driver compares the signal from the photodetector to the power level selected on its control panel. After making this comparison, the driver adjusts the radiofrequency (RF) drive signal to the a-o modulator, which controls the power level of the infrared (IR) input to the pulse compressor. The driver automatically restores lock if the detector signal is interrupted for any reason. Small variations in the amplitude and pulsewidth of the input to the pulse compressor cause fluctuations in the frequency-doubled output. By placing the modulator inside the Model 3800 cover between the laser and the pulse compressor, it is possible to both correct for input amplitude variations and make small changes in the input intensity to compensate for small fluctuations in the input pulsewidth. As a result, this scheme provides high levels of stabilized frequency-doubled output power with only small changes in the IR power.

Power Supply

The Model 3800 power supply delivers stable and reliable current regulation to the krypton arc lamp and ensures current regulation to less than 0.5% root mean squared (rms). A special isolation transformer permits operation with both 220- and 380-V line service. This unit contains a closed-cycle cooling system, including a deionized-water cartridge located on the back of the supply for easy access. A proportional valve controls the internal water temperature to within 0.5 ^{o}C. On the control panel, diagnostic readouts for the water temperature, water resistivity, and interlocks provide immediate update on the status of the laser system.

Mode-locked Operation

The Model 3242 mode-locking system combines precision mechanics with proven electronics to make mode locking easy and reliable. A mechanical assembly mounts the a-o

modulator near the output coupler. The modulator is an antireflection-coated, high-Q device. Because the device requires a low-level RF driver signal, the modulator needs no external cooling. A constant-temperature oven helps stabilize the acoustic resonance frequency. The laser-cavity-length adjustment is separate from the modulator assembly. The high reflector mount includes a locking micrometer that allows precise and repeatable matching of optical cavity length to the RF driving frequency of the modulator. Frequency stability of the mode locker is the key parameter for optimal synchronously (sync) pumped dye laser performance. The Model 452A mode-locker driver meets this need with an advanced temperature-stabilized frequency synthesizer. The overall frequency stability is better than one part in 10^8 with short-term frequency fluctuations (FM jitter) of less than 10 Hz (rms).

The mode-locker driver contains all control and diagnostic electronics: a frequency display with four significant digit accuracy, frequency scanning, and temperature stabilization. Optimum mode locking also requires precise matching of the driver frequency with the acoustic resonance of the modulator. The Model 453 mode-locker stabilizer monitors the relationship between the acoustic resonance and synthesizer frequencies. When the resonance and frequency differ, the stabilizer adjusts the power of the driver signal, which changes the temperature of the modulator and, with it, the acoustic resonance frequency. This feedback loop effectively locks the acoustic resonance to the synthesizer frequency, ensures optimum coupling of RF power into the modulator, and eliminates the problem of thermal runaway.

Pulse-compressed Operation

The Model 3695 fiber-grating pulse compressor shortens the <100-picosecond (ps) pulse from a mode-locked Model 3800 to less than 6 ps. This additional unit creates a solid-state, high-power, high-repetition-rate picosecond laser system. Fiber-grating pulse compression possesses several distinct characteristics that make it a powerful and useful technique. First, the input laser pulsewidth can be reduced by more than an order of magnitude. Second, efficient pulse compression increases the peak power of the optical pulse, which improves the efficiency of harmonic generation. Third, pulse compression takes place outside the laser cavity, permitting independent optimization of the laser source and the pulse compressor. Finally, pulse compression is a modular approach that can be used whenever greater time resolution or higher peak power is needed. The Model 3695 compressor operates at 1064 nm and uses a high-efficiency grating and a proprietary single-mode optical fiber to produce high transmission throughput in a compact package. At the input stage, a half-wave plate/polarizer/quarter-wave plate combination isolates the compressor from the Nd:YAG laser and serves as a convenient way to adjust the input power.

Frequency-doubled Operation

The Model 3225 frequency doubler doubles the frequency of the mode-locked compressed output of the Model 3800 with typical conversion efficiencies of up to 33%. This frequency doubler mounts directly in the pulse-compressor housing, producing high-power, high-repetition-rate picosecond pulses at 532 nm. Sync-pumping a dye laser with this output

produces pulsewidths of less than 500 femtoseconds (fs) with high average power. Both the angle and position of the potassium titanyl phosphate (KTP) crystal are adjustable for complete optimization of the frequency-doubled output. Lens assemblies focus the 1064-nm input into the crystal and collimate the 532-nm output. Adjustable dichroic beamsplitters separate the second harmonic from the fundamental and provide control over the alignment of the frequency-doubled output beam.

Model 3500 Ultrashort-pulse Dye Laser

The Model 3500 dye laser consists of a Z-fold optical cavity, precision mechanical controls, polished sapphire dye nozzle, and an optimized birefringent filter design coupled to a Model 3760 dye circulator.

Synchronous Pumping

The sync-pump dye laser system is comprised of a mode-locked pump laser and a dye laser whose cavity is extended so the intermode spacing is an integral multiple of the pump-laser mode-locker frequency. In this configuration, as each pump-laser pulse enters the dye stream, the leading edge of the pulse brings the population of excited dye molecules up past the lasing threshold. Because the pump cavity and the dye cavity are matched, the dye laser pulse circulating within the cavity is timed to arrive at the dye stream just as the dye laser medium reaches threshold. Because of the large stimulated emission cross section of the dye medium, the inverted population is rapidly depleted by the dye-laser pulse. This rapid "switch-off" of the gain medium is the reason for the generation of the very short pulses by the dye laser. Following this depletion, the remaining part of the pump pulse has insufficient energy to bring the dye laser back above threshold, so the resultant dye-laser pulse is much shorter in duration than the pump-laser pulse. Pulse repetition rate is determined by the pulse's round-trip time in the cavity. Reliable generation of ultrashort pulses requires critical stability of the mode-locker frequency source, the cavity length of the pump laser, and the cavity length of the dye laser.

Birefringent Filter

The birefringent filter is comprised of one or more crystalline quartz plates, placed in the laser cavity at Brewster's angle. The plates are cut parallel to their optical axes, and their birefringence causes the linear polarization of the incident laser beam to become elliptical. Only one frequency will make a complete 180-deg (or multiple thereof) polarization flip: the polarization of all other beams rotates more or less than that. The elliptically polarized beams suffer additional losses at other Brewster-angle cavity elements and fail to reach the lasing threshold. The free spectral range (FSR) of a multiplate birefringent filter is determined by its thinnest plate and is typically 80 to 100 nm. The FSR is the difference between adjacent eigenwavelengths (i.e., wavelengths that undergo a complete polarization flip). Rotating the filter around the axis normal to the plate changes its eigenwavelengths.

There are two types of birefringent filters. Each one is designed to optimize performance in a specific dye tuning range. The filter-plate thickness is chosen to maximize tuning linearity and wavelength discrimination and to minimize power loss through the tuning element. Additional plates sharpen the response of the filter by increasing its finesse. Each birefringent filter must be factory aligned for maximum tuning smoothness. All femtosecond systems use one-plate filters. In picosecond systems, performance requirements (i.e., pulsewidth) determine whether a two- or three-plate filter should be used. This system has three such filters, all designed to optimize performance using Rhodamine 6G dye: a one-plate for pulsewidths below 600 fs, a two-plate for around 1-ps pulsewidth, and a three-plate for 3- to 5-ps pulsewidths.

Resonator and Mirror Controls

The three-rod resonator forms a rigid structure that resists angular and thermal distortion. Mirror plates are precisely attached to the resonator bars to minimize mirror detuning and keep the output power constant. Graphite composite rods combined with a temperature-compensated design make the optical cavity insensitive to temperature changes. This design keeps the cavity length stable, giving uniform output pulsewidths. Mirror mounts operate smoothly and precisely with no backlash. The focus controls for P2, M2, and M3 (see Fig. 8) are independent of the vertical and horizontal alignment controls. This feature makes cavity alignment and focusing fast and accurate. The alignment controls for end mirror M1 are separate from the cavity length control. Cavity length can be adjusted to micron resolution without disturbing the alignment of M1.

Optics Selection

Each dye has a specific set of mirrors designed to optimize performance in that wavelength range. The combination of cavity mirrors that provide maximum dye laser performance depends on the desired output wavelength, the wavelength of the pump beam, and the gain characteristics of the dye. The pump mirrors have been selected to reflect wavelengths within the absorption spectrum of the dye. The end, focusing, and folding mirrors must reflect wavelengths within the tuning range of the dye. All optics for this system were designed for R6G dye and for wavelengths between 580 and 600 nm.

Cavity-dumped Option

The Spectra-Physics Model 3290 cavity dumper has been installed in this laser, and the laser may be operated in either sync-pumped mode or the sync-pumped, cavity-dumped mode. The cavity-dumped pulses cannot be amplified because the peak energy density of each pulse would be so large that the optics in the amplifier would be destroyed. With this cavity dumper installed, the sync-pumped laser provides a variable output pulse repetition rate and an increase of approximately 30 times the output pulse energy over the noncavity-dumped operation. The output pulsewidth is slightly longer but still under 1 ps for a one-plate birefringent filter installed. The Model 3290 cavity dumper is comprised of a Model 451

power-supply chassis, a Model 454 cavity-dumper driver, and a Model 3295 cavity-dumper head that is integrated into the Model 3500 dye-laser head.

Cavity dumping is a method of generating powerful pulses of laser light by diverting part of the energy stored within a closed resonant cavity. Unlike the pulse from a sync-pumped dye laser, whose power is limited by the transmission of the laser output coupler, a cavity-dumped pulse originates within the laser cavity, where as much as 75% of the circulating energy can be dumped into the output beam. An acousto-optic modulator is located in the cavity dumper between two curved mirrors creating a second waist within the laser cavity. The modulator (Bragg Cell) is an rf-driven transducer that generates a traveling acoustic wave across a fused silica block, whose shape prevents interfering reflections. Incident light interacts with the acoustic wave at the Bragg angle, and part of it is diffracted to another mirror which reflects the beam to the outside of the cavity. The output of a mode-locked, cavity-dumped system maintains the mode-locked pulsewidth but with both enhanced power (about 30 times that of a mode-locked pulse) and variable repetition from single shot to 4 MHz. Rejection of secondary pulses is high (1000:1) due to a Spectra-Physics proprietary integer-plus-one-half time technique. The output remains tunable over the range of the dye.

Model CPA-2 Fiber Prism Compressor

The Model CPA-2 compressor consists of two separate modules: the fiber module and the rephasing module. In the fiber module a pulse is "chirped," broadened both spectrally and in time. The rephasing module is used to rephase the spectrally broadened pulse in time thereby giving rise to a compressed pulse.

Pulse compression has several characteristics that make it a powerful and useful technique. First, the input pulsewidth can be reduced by more than a factor of five. Second, efficient pulse compression increases the peak power of the optical pulse. Third, pulse compression occurs outside the laser cavity, which permits independent optimization of the laser source and pulse compressor. Finally, pulse compression is a broadband technique that can be applied to many different laser systems. A modular approach allows it to be used whenever greater time resolution or higher peak power is needed.

The fiber module contains a short length of single-mode polarization preserving fiber, input and output fiber couplers as well as half-waveplates before and after the fiber. The fiber length is approximately 15 in. Due to the extremely high peak power involved, pulse chirping occurs in the first few inches, and the excess length facilitates handling. The input waveplate is used to rotate the input polarization to the fiber because this fiber has a preferential polarization for optimum efficiency. Proper polarization matching is evidenced by maximum chirping. The output waveplate is used to rotate the output polarization to match the next stage (the rephasing module requires vertical polarization).

The rephasing module contains a highly dispersive prism and an adjustable delay line as well as input- and output-turning mirrors. The beam enters the module and is steered toward the dispersion prism by the input-turning mirror.

At this point, the beam passes through the dispersion prism high with respect to the vertically mounted baseplate and near the lower tip of the prism. The input-turning mirror is used to route the beam to the near-lower face of the first folding mirror. The beam is then steered toward the near-lower face of the second-fold mirror by adjusting the first fold mirror. The second fold mirror is used to steer the beam to the near-lower face of the sliding delay prism and parallel to the sliding delay prism rail (vertically and horizontally). The beam passes through this 180-deg turning prism high with respect to the vertically mounted baseplate and returns toward the dispersion prism through fold mirrors 1 and 2. The tilt of the sliding delay prism is adjusted to maintain a parallel beampath, while the up/down position is adjusted for proper beam spacing through the dispersion prism. Next, the beam passes through the 180-deg, step-down prism which is positioned to redirect the beam back along the original path but closer to the vertically mounted baseplate. After passing through the dispersion prism, the beam is steered out the output port of the module by the output-turning mirror. Various possible positions of fold mirror 1 provide for course adjustment of the delay line. Normally, this mirror should be placed so that the sliding delay prism is near the middle of its adjustment range when the pulsewidth has been optimized.

The rotational orientation of the dispersion prism controls the rate of dispersion compensation in the delay line. However, if a longer delay line than is possible is required, rotating the dispersion prism counterclockwise (CCW) increases the dispersion through the prism though adversely affecting overall throughput and beam quality. Therefore, rotational adjustments should be made in increments of only a few degrees at a time. When rotational changes are made, the input-turning mirror will require adjustment to reroute the beam to the folding mirror. The purpose of the delay line is to compensate for dispersion in the fiber. Sliding the prism assembly provides a means of course adjustment, while translating the dispersion prism allows for fine adjustment.

Model PDA-L3 Pulsed Dye Amplifier

The Model PDA-L3 amplifier consists of a box containing three stages of amplification together with optics and a Model TSC-2 dye circulator. This circulator consists of two independent dye circulation systems. Each system contains a pump, filter, reservoir, and hoses. The first two amplification stages use one circulation system, while the final stage requires a lower dye concentration which is provided by the other TSC-2 circulation system.

The PDA-L3 system amplifies tunable input pulses throughout the visible and near IR. Tuning is accomplished by scanning the input wavelength within the tuning range of a given amplifier dye. No saturable absorbers or dispersive optics are used. This unit was designed to be pumped by the GCR-3RA Nd:YAG laser with a regenerative amplifier and amplifies pulses of less than 1 nJ each from the Model 3500 dye laser to at least 100 μJ per pulse in the

femtosecond range of pulsewidths. This unit is capable of working with many different dyes; however, in this case, Kiton Red 620 dye is used. Dye concentrations for the oscillator stage (first two stages) use a concentration of 20 mg/l with methyl alcohol as the solvent. The third stage (amplifier) uses a dye concentration of 8 mg/l with the same solvent. Overall gain is at least one-half million.

Model GCR-3RA Pulsed Nd:YAG Laser with Regenerative Amplifier

The Model GCR-3RA consists of several units including a Gaussian coupled resonator or laser head, a regenerative amplifier utilizing a second Nd:YAG rod, a fiber-optics seed-pulse delivery system, second harmonic generator or frequency doubler (HG-2) for 532-nm outputs, and a power supply. A Model SM-1 synchronization module is also added to the system to synchronize the firing of the first or input Pockels cell of the GCR with the mode-locked laser.

This optical regenerative amplifier repetitively amplifies the seed pulses being supplied to it from the Model 3800 laser through the fiber-optic system. An unstable resonator-equipped oscillator is used as the regenerative amplifier to give shape and spatial uniformity to the picosecond pulses. Use of an unstable resonator allows the laser to maintain large mode volume in order to minimize peak power density and prevent optical damage. In this system, the regenerative amplifier is configured as an oscillator-amplifier scheme. This approach is required to produce high-energy picosecond pulses without damage to the Pockels cells or other resonator components. The GCR employs an unstable optical resonator in which the reflectivity of the output coupler decreases as a function of distance from the center of the optic in a Gaussian-like manner. As a result, this unit sustains a large mode volume in the Nd:YAG rod while discriminating against higher order transverse modes. The unit delivers a smooth spatial beam profile in a single transverse mode while retaining the high-energy and long-term stability characteristics. A continuously simmered flash lamp and self-contained, closed-loop cooling with deionized water increase the consistency of lamp discharges. Also, the whole resonator is kinematically mounted to mechanically isolate it from its environment. Thus, it has very high pulse-to-pulse energy stability, beam-pointing accuracy, consistent spatial energy distribution, and temporal jitter.

The resonator is a high-magnification, unstable resonator, formed by two reflectors--High Reflector 1 and High Reflector 2. An aperture is located within the cavity to provide spatial mode control. An "S"-polarized seed pulse derived from the mode-locked Model 3800 is optically injected into the resonator using the input-polarizer, Pockels cell/quarter-wave plate assembly. The "S"-polarized pulse has a polarization perpendicular to the optical table. A pulse with this polarization will be reflected off of the input dielectric polarizer and into the optical resonator. The input Pockels cell, without high voltage applied, will not alter the polarization of the seed pulse. A double pass through the quarter-wave plate results in a 90-deg polarization rotation of the seed pulse. Now, horizontally or "P" polarized, the seed pulse travels through the input polarizer, output polarizer, Nd:YAG gain medium, and output Pockels cell. Upon reflection off of High Reflector 2, the seed reverses its path through the

resonator, once again being amplified by the Nd:YAG gain medium. If the input Pockels cell is still without high voltage, the seed pulse continues to follow its original path and is ejected from the cavity. If high voltage has been applied to the input Pockels cell, the Pockels cell negates the polarization rotation of the quarter-wave plate, and the seed pulse retains a horizontal or "S" polarization. The seed pulse is now trapped in the cavity, and other potential seed pulses are excluded. After 6-8 round trips in the resonator cavity, the seed pulse has been amplified by $\sim 10^6$. At this point, the pulse has developed into a high-power (~ 1 gW/cm^2), spatially uniform pulse. Application of high voltage to the output Pockels cell rotates the polarization of the high-power pulse. The pulse is reflected off the output polarizer and ejected from the resonator.

After beam expansion and collimation, the pulse undergoes amplification with a single pass Nd:YAG amplifier assembly. An internal photodiode is located immediately after High Reflector 2 of the resonator. Trace light leakage is detected by this photodiode. A cable on the GCR allows access to the monitor detector. This detector is useful in monitoring the amplification or buildup of the picosecond laser pulse. The photodiode must be terminated with 50 ohms.

OPERATING PROCEDURES

I. SECURE ROOM

A. Turn on "DO NOT ENTER" illuminated sign.

B. Close all doors to laboratory.

C. Clear optical bench of all material extraneous to experiment.

D. Personnel in the room should be wearing proper eye protection.

II. TURN-ON PROCEDURE

A sequential instrument-by-instrument turn-on procedure is required to operate this system, because each stage requires the correct output power and pulse shape of the preceding stage in order to operate correctly. Thus, the turn-on procedure will be given on an instrument-by-instrument basis.

A. MODEL 3800 LASER SYSTEM POWER SUPPLY (See Fig. 2)

1. Ensure Shutter switch is in the "Closed" position.
2. Turn Main Power key switch momentarily to the "Pump Start" position. Return it to the "On" position after internal pump has started.

3. Turn on water supply.
4. Press Power Supply "On" switch after start-up delay. Green light should illuminate.

B. GCR POWER SUPPLY (See Fig. 3)
1. Ensure that both Lamp Energy Adjust controls are fully CCW on GCR.
2. Turn key switch to "On" position.
3. Set Laser circuit breaker to "On" position.
4. Set Amplifier circuit breaker to "On" position.
5. Turn on water faucet supply one-quarter turn only. Check for pressure in hose at Power Supply.

C. MODEL GCR-3RA (See Fig. 4)
1. Press Oscillator "On" button. The green and red lights in the oscillator section should illuminate.
2. Press Amplifier "On" button. The green and red lights in the amplifier section should illuminate.

D. MODEL 3800 LASER SYSTEM POWER SUPPLY
1. Wait for Lamp Start button to illuminate.
2. Press Lamp Start button. Light should extinguish and current meter should move up scale. Repeat if lamps fail to start. If lamps fail to start after a few tries, refer to manual for Model 3800.
3. Wait 45 min for Model 3800 laser to warm up.

*** WARNING *** WEAR EYE PROTECTION FOR 1064-nm WAVELENGTH WHILE PERFORMING ADJUSTMENTS IN STEP E.

E. MODEL 3695 OPTICAL PULSE COMPRESSOR (See Fig. 5)
1. Remove cover from Model 3695.
2. Place Coherent Model 210 power meter head between polarization rotator R2 and optic fiber chuck assembly.
3. Set Model 210 power meter to 10-W scale.
4. Set Shutter switch on Model 3800 power supply to "Open" position. Check for proper mode-locked pulse train of the Model 3800 on an oscilloscope (see Model 3800 manual). If pulse train is improper, make necessary adjustment according to the Model 3800 manual. **Note:** From this point on, adjust range switch, on Model 210 power meter, as needed.
5. Adjust polarization rotator R1 to obtain a 1-W reading on power meter.
6. Adjust optic fiber chuck assembly to obtain at least 50% of input power at output of polarization rotator R4.
7. Repeat step E.2.
8. Adjust polarization rotator R1 to obtain a 3-W reading on power meter.
9. Repeat step E.6.

10. Repeat step E.2.
11. Adjust polarization rotator R1 to obtain a 6-W reading on power meter.
12. Repeat step E.6.
13. Repeat step E.2.
14. Adjust polarization rotator R1 to obtain maximum reading on power meter.
15. Repeat step E.6.
16. Place Model 210 power meter head at output of Model 3695.
17. Adjust Model 3695 as needed to obtain as close to 1 W or more as possible.
18. Install cover on Model 3695.

OPTIMIZING PROCEDURES

The adjustments in II.E (Operating Procedures) are adequate if system alignment is maintained and no changes have occurred. However, many times the 1 W required at output cannot be obtained, and more adjustments are required to obtain the desired output power. The readings on the meter at each step are important in reaching the required output. The following description follows the actual adjustments required and is written from experience and not system manuals. If the 1 W of power from the Model 3695 cannot be obtained as outlined in II.E, continue as described in this section.

Starting with step E.5, it is not critical to have exactly 1 W on the power meter. The only reason to start out with low power is to avoid burning the end of the fiber with high power when first turning on the system. One watt is a satisfactory value, and if it is the value, the reading at the output of R4 as in step E.6 should be 50% or higher. The adjustments to be made to peak the power value will normally be on the fine-adjustment end (end with the microscope objective and iris) of the optic fiber chuck assembly. Course-end adjustments will not allow the fine tuning required for peaking. Keep the power output from the fiber at least 50% of the input, only for the higher power levels. At step E.8, for 3-W input to the fiber, the fiber output will normally be between 1.6 to 1.8 W and can be routinely obtained by adjusting the fine adjustments and the focus control (Z-axis or longitudinal) on the fiber chuck at the input. This screw focus adjustment is very critical and should be rocked back and forth to obtain peak power. No adjustments on the output end of the fiber should be made at this time. A reading of over 50% or 3 W should be obtained at step E.11 for 6-W input, and in step E.14, when adjusting for maximum power input, the value should be at least 9 W. It really does not matter what the input power is as long as a reading of greater than 5 W can be obtained at the output of the fiber. Normally after the system has warmed up satisfactorily, a power of 5.5 W can be obtained by doing the fine adjustments and focus or Z-axis control. This value is necessary to obtain the 1-W output at 532 nm from the doubler.

Another adjustment which may be considered in tweaking the power is the alignment of the beam input to the fiber-optics microscope objective. This adjustment requires the rocking back and forth of both vertical and horizontal adjustments on the fine controls of the holder,

and the vertical and horizontal mirror adjustments on the corner mirror closest to the Model 3695 input end. These adjustments are known as "walking" the beam to optimize its angle of incidence on the face of the fiber. By adjusting both vertical (or horizontal) controls sequentially back and forth or "walking," the power can be peaked in both directions (vertical and horizontal).

> **CAUTION:** These adjustments are very critical. Only very, very small movements at a time should be made because large adjustments can offset the beam enough to damage the fiber end.

If all of the earlier adjustments fail to provide over 5 W of output power for an input power of at least 9 W to the fiber, most likely the fiber end at the input has been damaged and requires cleaving. Refer to the manual on the Model 3695 for the cleaving procedures. For a power level 5 W or greater from the fiber output, the power measured between routing mirrors M1 and M2 must be 3 W or greater. In other words, the power to the frequency doubler must be 3 W for this unit to double satisfactorily and give an output of 1 W at 532 nm. Even for 3-W input, some adjustments are required on the frequency doubler to give the correct output. However, it is not always easy to obtain the 1-W output power for even 5.5 W from the fiber.

According to step E.17, the Model 3695 is adjusted as needed to obtain a 1-W output or more from the frequency doubler. A number of adjustments may be required before obtaining this value. For instance, the input polarization rotator R2 and polarization rotators R3 and R4 usually require adjustment every time the fine frequency is changed. Also, in some cases, the delay prism P1 must be adjusted whenever the unit is turned on. To maximize the 532 nm, the two adjustment knobs on the frequency doubler may need adjustment. Thus, the procedure to optimize the Model 3695 usually starts with the power output being monitored, while the three polarization rotators are adjusted sequentially, back and forth, to obtain peak power. After no increase in power is observed for a rotation in either direction of any of the three rotators, the delay prism P1 should be moved in either direction and its knob on top adjusted to peak the power reading. If 1 W still cannot be achieved, the process should be continued by tweaking the routing mirror M1, polarization rotator R5, and the two knobs on the frequency doubler. It usually takes several iterations of adjusting the polarization rotators, delay prism, routing mirror, and frequency doubler to achieve over 1 W in output power.

The dichroic beamsplitters do not require adjusting to achieve maximum power; however, they do require adjusting when directing the beam through the Model 3275 a-o stabilizer and into the dye laser. After 1 W has been reached at the output of the Model 3695, move the power meter to a position between the a-o stabilizer head and the dye laser to monitor the power after the detector. At this time, the signal from the photodetector can be monitored on the oscilloscope and the power to the laser measured. It is necessary to observe this signal on the oscilloscope to minimize the noise and to ensure that the a-o stabilizer does indeed eliminate the fluctuations, and the noise has been eliminated after activating this stabilizer.

*** WARNING *** WEAR EYE PROTECTION FOR 532-nm WAVELENGTH WHILE PERFORMING ADJUSTMENTS IN STEP F.

F. MODEL 3275 ACOUSTO-OPTIC STABILIZER (See Fig. 6)

1. Ensure Servo Loop switch is in the "Off" position.
2. Ensure Mode switch is in the "Stabilized" position.
3. Ensure Monitor switch is in the "Light Level" position.
4. Ensure Level control is fully clockwise (CW).
5. Place Model 210 power meter head between photodetector assembly and the Model 3500 dye laser.
6. Adjust Hi/Low Attenuator control on the photodetector assembly for a reading between 8 and 10 on Model 3275 meter.
7. Set Servo Loop switch to "On."
8. Adjust Level control for a reading of 800 mW on the Model 210 power meter. Observe a-o stabilizer signal on oscilloscope to check for stability. Adjust Fine Frequency adjustment on Model 452 mode locker if signal is noisy and repeat steps E.17 and E.18.
9. Remove Model 210 power meter head from beampath.

To activate the Model 3275 a-o stabilizer, follow steps F.1 through F.9 and make adjustments accordingly. If the a-o stabilizer does not give a flat line on the oscilloscope, adjustments of the system must be made to reduce the noise level before turning on the stabilizer. This adjustment can be accomplished by making a number of tweaking procedures in different components in the system. The order of tweaking the system should start with the fine frequency adjustment on the mode locker, then the frequency doubler knobs, and all adjustments on the fiber-grating compressor. Finally, if all other adjustments fail to give the desired effect, adjust the cavity length on the Nd:YAG laser.

G. MODEL 3500 DYE LASER (See Figs. 7, 8, & 9)

1. Turn on Model 409 autocorrelator and connect to oscilloscope. See Model 409 manual for proper connection.
2. Ensure dye catcher tube assembly is pushed all the way in.
3. Set the Model 3760 power On/Off switch to the momentary position long enough to allow the pump start. Then allow the switch to return to the "On" position.
4. Ensure that pressure on pressure gauge is above 80 psi.
5. Place Model 210 power meter head at output of Model 3500.
6. Pull dye catcher tube assembly back until it reaches the stop. Then pull return tube back another 0.125 in.
7. Adjust Model 3500 for maximum output at desired wavelength. In most cases, the only adjustments required are the external beam positioning and cavity length. Refer to Model 3500 manual for optimizing dye laser.
8. Remove Model 210 power meter head from beampath.

9. Observe autocorrelation signal on the oscilloscope (some adjustment of autocorrelator may be necessary).
10. Using autocorrelation signal, optimize the shape, width, and stability of the pulse using the cavity-length adjustment.
11. Measure the output power of Model 3500 with Model 210 and note value.
12. Align beam into chirper so that about 50% of the power at output of Model 3500 is present at the output of chirper. Use Spectra-Physics Model 401 power meter to measure chirper output.

The Model 3500 dye laser can be set up and operated according to steps G.1 through G.12 in the start-up procedure. However, because there are 21 knobs on the laser that can be adjusted to optimize the output pulsewidth, power level, and wavelength, it can be a tedious job to learn what effect each knob has on the pulses. Fortunately, most knobs rarely need tweaking, and the majority of adjustments will be for maximizing the power output and minimizing the pulsewidth. Only six knobs receive the majority of adjusting, and these can be quickly learned. Because the cavity is in the form of a folded-Z configuration, the horizontal and vertical adjustment knobs for the mirrors M1 through M6 rarely need adjustments, so 12 of the 21 knobs can be left alone. The two knobs on the nozzle control do not require adjusting except while setting up the system so they can be left alone. The micrometer control on the birefringent filter control only needs adjusting if the wavelength is going to be changed.

Therefore, the other six knobs will be adjusted routinely to optimize the output. Of these six knobs, only three are accessible from the outside of the Model 3500 cabinet so that once the laser has been tuned and the cover put on, only three knobs need adjusting. The three internal adjustments are the three focusing mirrors: focusing mirrors M2 and M3 and pump-focusing mirror P2. The three external controls are the two knobs on the pump-folding mirror P1 (horizontal and vertical control) and the cavity length adjustment on M1, which is located at the beam input end. This cavity length can be adjusted to micron resolution without disturbing the alignment of M1. This cavity length will normally be used for setting the pulsewidth because the pulsewidth is shortened as the cavity length is shortened. This adjustment will always be made while observing the shape of the pulse as a function of time from the autocorrelator on the oscilloscope.

After following steps G.1 through G.9 in setting up the dye laser and observing a signal from the autocorrelator, the procedure for performing step G.10 to optimize the shape, width, power, and stability of the pulse will be given. The power meter head should now be placed after the beamsplitter supplying the pulse to the Model 409 autocorrelator so that the autocorrelated signal and the power output can be monitored simultaneously. Monitoring both signal and power output while optimizing each is necessary because they affect each other so strongly. Whenever the wavelength micrometer is set to 237 on its dial (i.e., 12 on the barrel), the wavelength is ~575 nm and is the greenish-yellow color. For this value, the power measured by the meter should be at least 135 mW after the beamsplitter. Adjust both external beam-directing controls to give this power. There are two possibilities that might cause this power level not to be obtained: misalignment of the dye laser or a problem with the pump

beam. First, check to make sure that the pump beam is hitting the center of the pump mirror (P1) and is in the center of the spring clip holding that mirror. If not, readjust the beam position using the dichroic mirrors in the output of the Model 3695 and make sure that the stabilizer is not affected. The cover of the dye laser must be removed to observe the position of the pump beam. Now, readjust all three of the focusing mirrors (M2, M3, and P2) for a maximum power of >130 mW. The autocorrelation trace should be visible but may show a very wide signal. By turning the cavity length adjustment of M1 CCW, which increases the length, the pulsewidth will become broader. For CW rotation, the pulsewidth decreases. The normal tweaking procedure will be to start with CCW rotation to ensure a stable, very broad pulse and then rotate it CW to minimize the pulsewidth. The oscilloscope trace can be calibrated using the thin calibration etalon inside the autocorrelator which gives a delay of 3.87 ps in time when the etalon is in the beampath only once. The peak of the autocorrelation signal will be translated on the oscilloscope faceplate an equivalent amount when using this etalon. Thus, if full width-half maximum (FWHM) as shown on the oscilloscope is measured to be 0.4 division and the delay calibration is 2 divisions, the actual pulsewidth is 0.4 divided by 2 times 3.87 ps times 0.65 equals 500 fs FWHM. For the minimum pulsewidth obtainable, the oscilloscope trace will show wings of about 10%, and the pulsewidth will be around 300 fs. The desired result is to obtain this short pulse with at least 130 mW power output.

The chirped pulse from the Model CPA-2 fiber chirper as obtained in step G.12 does require tweaking in most cases to obtain the required output power. The power level from the Faraday rotator at the output of the chirper should be at least 50 mW; however, many times it will take a lot of adjusting to reach this level. This 50 mW is one-third of the 150 mW which can be measured directly from the output of the dye laser. The required tweaking consists mainly of adjusting the two knobs on the first turning mirror past the dye laser and the fine controls (horizontal and vertical) on the fiber-optics holder in the chirper. Sometimes it is very difficult to obtain the 50 mW and the above controls have to be tweaked simultaneously, both horizontal and then both vertical. The same procedure is used in the Model 3695 to "walk" the beam into the fiber end to optimize the angle of incidence to it. Several iterations of both horizontal and vertical tuning may be required before obtaining the correct power levels.

After obtaining the correct power level through the Faraday isolator the next step is to direct the laser pulses through the delay line, through the pinhole to the Model PDA-L3 pulsed dye amplifier, through this unit's three dye cells, and out through the rephasing module of the CPA-2 compressor. The difficulty with this step is the necessity of adjusting the delay line almost every time the unit is operated. Whenever the delay line is adjusted, the laser beam must be redirected to the center of the pinhole in the Model PDA-L3 and, therefore, throughout the rest of the system. The delay line must be readjusted every time the delay prism in the Model 3695 pulse compressor is moved or adjusted during the startup procedure. This delay line compensates for the changes in timing of the pulses arriving in the dye cells in relation to the pump pulses from the Model GCR-3RA.

H. MODEL GCR-3RA (See Fig. 10)

1. Ensure Q-switch is set to "SS/Remote" on both the remote control and GCR.
2. Ensure Lamps switch on remote control is set to "On" position.
3. Ensure Pulse Rep. Rate is set to "10 Hz."
4. Ensure both Sim. On lights are illuminated. If they are not illuminated, refer to manual for GCR.
5. Slowly rotate both Lamp Energy Adjust controls fully CW.
6. Press Seeding switch which is located between the Lamp Energy Adjust and the Variable Pulse Rep. Rate controls on the oscillator section of the GCR. The green light beside the Seeding switch should illuminate. If it does not illuminate, refer to the GCR manual.

I. MODEL PDA-L3 (See Fig. 11)

1. Set Dye Oscillator Pump switch to "On" position.
2. Set Dye Amplifier Pump switch to "On" position.
3. Using the two external mirrors that are placed after the optical delay, align the Model 3500 beam into and through the PDA.

The procedure for adjusting the delay line includes maximizing the power out from the PDA when the input pulses are being amplified. This delay line does not affect the pulses going through the PDA, and no difference is notable if the GCR pump laser is not on. It is necessary to first set up the dye amplifier with pumps on and the pump laser off and to adjust the optics to allow the pulses to pass completely through the PDA without being clipped. Thus, it is necessary to first direct the beam to the pinhole at the input of the dye amplifier. Minimum scatter should be observed at the pinhole as the beam passes into the PDA and strikes the corner mirror near its center. Using a white card just past the first dye amplifier to observe the spot size, adjust the optics for the pattern to be a bright center spot surrounded by concentric circles. This pattern is produced by the second pinhole in the baffle immediately after the dye cell. The beam must pass through the center of the dye cell and strike the pinhole. This adjustment is the most difficult of all because in most cases the beam must be "walked" by the outside beam-directing mirrors to give the correct angle of incidence to the PDA. There is an aid in obtaining this correct angle of incidence by observing the reflected spot inside the PDA to return to a mark on a piece of paper placed beneath the input pinhole. When the reflected beam hits this spot and the reflected concentric ring pattern produced by the second pinhole overlays the input pinhole disc, the optics are closely aligned. After observing the image past the first dye cell, move the card to a position past the third dye cell and observe the spot pattern. Anywhere past the third dye cell, the spot on the card should be one large, circular spot surrounded by a thin dark ring. As the optics are adjusted to try and obtain this large circular spot, the spot will change shapes and no longer be circular if misadjusted. All adjustments to obtain the correct pattern and spot size must be made on the two reflecting mirrors outside the PDA and the delay prism control.

No adjustments on the PDA need to be made at this time. After passing through the PDA, the laser beam should be directed to the Scientech power meters to measure its power

after the PDA. The power should be measurable but in most cases will be less than 50 μW. When the GCR pump laser is turned on, the power level must increase by at least 1 mW to give at least 100 μW per pulse output. However, if the delay prism in the Model 3695 pulse compressor was adjusted during initial setup, most likely the output power from the PDA will be much less than 1 mW, and in many cases there will be no amplification at all. This problem of no amplification always occurs when the delay has been changed enough so that the pulse to be amplified does not arrive in the dye cell at the same time as the pump pulse. Mistiming is a common occurrence because the pump pulse is only 50 ps long and light travels only one-half inch in space during this 50 ps. Thus, it is easy to understand why the delay line must be adjustable to compensate for delays occurring anywhere in the system.

If the beam through the PDA is aligned properly and the pump laser is turned on but there is no amplification, the procedure to find the correct delay so that amplification can occur is to move the delay prism in the delay line one direction and retune and check for amplification. Be sure to turn off the pump laser when adjusting the delay line so that the beam spot size and shape can be observed past the PDA after the delay has been adjusted. Keep moving the delay prism in the same direction until amplification occurs or the end of the adjustment is reached. If no amplification happens in this direction, move the prism back to the starting point and move it in the other direction until amplification. Move this prism in very small increments of no more than one-quarter of an inch to make sure that the correct timing is not missed. After it has been observed that some amplification is occurring, it is necessary to optimize the delay for maximum amplification. Continue the movement of the prism until the power out peaks and starts to decrease, then move it in the other direction until the peak has been reached again. This adjustment will be the correct delay for maximum power output.

The last and most critical adjustment is to determine the pulsewidth after passing the pulse through the CPA-2 rephasing module. After this module, the pulse should be sent to the Model 5-14-LD slow-scan autocorrelator for measuring its pulsewidth. The turning mirror on the outside of the rephasing module should be adjusted to direct the laser beam to the adjustable iris at the input of the autocorrelator. The pulsewidth as measured by the autocorrelator can be recorded on either the Model SE 420 strip-chart recorder or measured by the Prowler digital oscilloscope with a readout and plotted on the Model 7047A X-Y recorder. If the autocorrelation signal is only recorded on the strip-chart recorder, the width must be calculated from the recording.

Setting up the autocorrelator to measure the pulsewidth can be difficult sometimes because it is necessary to ensure that the signal being measured is truly the autocorrelation signal and not from one of the arms signal. The signal level on the meter of the autocorrelator must change from a high level ~4-5 when the center light is on to a low level of ~1 when the start light is on. A true autocorrelation will give a large change as the moveable arm goes back and forth from start to center.

CAVITY-DUMPED OPERATION

To operate the Model 3500 dye laser in the sync-pumped, cavity-dumped mode, the laser must be reconfigured for cavity-dumped operation. The cavity-dumper head was designed to remain inside the Model 3500 even while operating in the sync-pumped mode by removing a single mirror, M6 (see Fig. 12) and bypassing the cavity dumper. This mirror is reinstalled for the cavity-dumped operation. Mirror M8 (with the red knob) is moved over to pick off the dumped beam, and M1 is repositioned to optimize the pulsewidth. The only other change is that the output-end mirror for sync-pumped operation is removed and a periscope is installed in its place to transfer the output beam through the end plate of the laser. When the laser is returned to sync-pumped operation for amplifying single pulses, the reverse process must be carried out. Coarse alignment of all of the mirrors and the Bragg cell adjustments are individually described and explained in the instruction manuals for the Model 3500 ultrashort-pulse dye laser and Model 3290 cavity dumper. These manuals must be consulted to obtain initial lasing when the unit is switched over to cavity-dumped operation.

When switching from the sync-pumped operation to cavity dumping, it is very important to make sure that all beams strike the center of each mirror when the unit is lasing and no obstruction is possible. Only the end mirror, M1 (see Fig. 8), requires repositioning for the unit to lase in the cavity-dumped operations. No other mirror needs to be moved. The M1 end mirror must be moved inward to shorten the cavity length to maximize the power out and minimize the pulsewidth.

Obtaining lasing in the cavity-dumped mode is not usually difficult; however, obtaining the specified power output at the specified pulsewidth can be very difficult. The key requirement for lasing is that the beam folds back onto itself from the cavity dumper to mirror M4 (as observed through a pinhole) (refer to Fig. 12) and all the way back to M1, the end mirror. After lasing is achieved with a repetition rate of 4 MHz on the cavity dumper, optimizing adjustments are made while observing the pulsewidth on the Model 409 autocorrelator and monitoring the power output after a beamsplitter.

After lasing is achieved, the first check is to determine if the laser is operating in a single mode. This step is accomplished by using a diverging lens placed in the beam after it exits the laser and displaying the expanded beam on a piece of white paper. **CAUTION!!! USE A PAIR OF SAFETY GLASSES WITH AT LEAST 3 O.D. AT 580 NM WHEN OBSERVING THIS EXPANDED BEAM ON THE PAPER.** The correct spot from the expanded beam will be a round, Gaussian profile without any shaded areas or half-moon shapes observable. The image may split into two spots when either of the pump folding mirrors P1 (horizontal or vertical) is rotated back and forth for the brightest spot. The Bragg cell focus spot control should be adjusted to obtain the single spot as observed in the expanded beam.

To optimize the output power and the pulsewidth, it is necessary to switch back and forth between adjusting for maximum power and minimum pulsewidth. These are not always

easily obtained. To obtain maximum power, adjustments on M1 (vertical and horizontal), P1 (vertical and horizontal), and the three adjustments on the Bragg Cell, scan, angle, and tilt controls are made repeatedly. Over 200 mW can be obtained easily, but when the cavity length adjustment, M1, is made to shorten the pulsewidth, the output power is always reduced. The desired endpoint is to obtain a pulsewidth of around 600 fs and 200 mW output power at 4 MHz.

SHUTDOWN PROCEDURES

III. SHUTDOWN PROCEDURE

A. MODEL GCR-3RA

1. Set Q-switch switch to "SS/Remote" on the GCR remote control.
2. Turn both Lamp Energy Adjust controls fully CCW.
3. Press the "Off" button for both the Amplifier and Oscillator sections.

B. MODEL PDA-L3

1. Set the Pump switch for both the Oscillator and Amplifier to the "Off" position.

C. MODEL 3500 DYE LASER

1. Push catch tube assembly all the way in.
2. Push return tube in an additional 0.125 in.
3. Set On/Off switch to the "Off" position on the Model 3760.
4. Turn off the Model 409 autocorrelator.

D. MODEL 3275 ACOUSTO-OPTIC STABILIZER

1. Turn Level control fully CW.
2. Set Servo Loop switch to the "Off" position.

*** WARNING *** WEAR EYE PROTECTION FOR 1064-nm WAVELENGTH WHILE PERFORMING ADJUSTMENTS IN STEP E

E. MODEL 3695 OPTICAL PULSE COMPRESSOR

1. Remove cover of Model 3695.
2. Adjust polarization rotator R1 for minimum output of Model 3695.
3. Install cover on Model 3695

F. MODEL 3800 POWER SUPPLY

1. Set Shutter switch to the "Closed" position.
2. Press Power Supply "Off" switch.

G. GCR POWER SUPPLY

1. Set Amplifier circuit breaker to the "Off" position.
2. Set Laser circuit breaker to the "Off" position.
3. Set Key switch to the "Off" position and remove the key.

H. MODEL 3800 POWER SUPPLY

1. Ensure Main Power "Off" button is illuminated. If not, repeat step F.
2. After 5 min from time the Power Supply "Off" button was pressed, turn off water supply.
3. Turn Main Power switch to the "Off" position and remove key.

DIAGNOSTIC INSTRUMENTATION

Many diagnostic instruments are required to set up the system and monitor the outputs from each of the subsystems. Also, during the setup and turn-on procedures, the power levels and pulsewidths must be observed and optimized before the desired output pulsewidths and energy levels can be obtained. The following instruments and measuring systems are required for these measurements:

- Model 210 Power Meter, Coherent Radiation, 300 mW to 10 W, Full Scale
- Model 401 Power Meter, Spectra-Physics, 1 mW to 100 mW, Full Scale
- Model 365 Power/Energy Meter, Scientech, Inc. Head Model 380101 calibrated 20 μW to 20 W, Full Scale
- Model 2235 Oscilloscope, Tektronics, Inc. 100 MHz, dual-time base, 2 channel scope
- Model 7834 Storage Oscilloscope, Tektronics, Inc. 300 MHz with plug-ins installed--2 7A24 amplifiers and 7B92A and 7B85 time bases
- Model 409 Scanning Autocorrelator, Spectra-Physics, 30 ps to 100 fs
- Model 5-14-LD Slow-scan Autocorrelator, Inrad, Inc. 10 ps to 50 fs
- Model AR-S3 Photodetector, Antel Optronics, Inc. 50-ps risetime
- Model 11800 Series, Digital Sampling Oscilloscope, Tektronics, Inc., 17.5-ps risetime, 2 channels
- Model PROWLER, Digital Oscilloscope, Norland, Inc., digital storage scope
- Model 7047A X-Y Recorder, Hewlett-Packard, Inc., servo-controlled recorder
- Model SE 420 Chart Recorder, BBC Goertz Metrawatt, Inc., strip-chart recorder
- Model 82-410 Ebert Scanning Monochromator, Thermo Jarrell Ash Corp. w/Model SD85 Scan Controller, Spectradata GmbH, Federal Republic of Germany.

SYSTEM SPECIFICATIONS AND CAPABILITIES

1. Model 3800 Nd:YAG Mode-locked Laser
   Characteristics
   Wavelength = 1064 nm

Continuous-wave Mode-locked Laser*
Power out = 1.1E+01 W
Beam Diameter = 1.00E-01 cm at 1/e points
Divergence = 1.00E- 03 radians full angle at 1/e points

*Mode-locked Rep. Rate = 82 MHz
Pulsewidth = 80 ps
Peak power = 1.2 kW per pulse

2. Model 3695 Pulse Compressor/Frequency Doubler
Characteristics
Wavelength = 532 nm*
Pulse compressed/Frequency doubled
Power out = 1.0E+00 W unstabilized
8.0E-01 W stabilized
Beam Diameter = 1.00E-01 cm at 1/e points
Divergence = 7.00E-04 radians full angle at 1/e points

*Mode-locked Rep. Rate = 82 MHz
Pulsewidth = 5 ps

3. Model 3500 Dye Laser
Characteristics
Wavelength = 580 nm
Input Pump Pow[illegible]00 mW @ 532 nm
Average Power [illegible]E-01 W*/**
Beam Diameter = [illegible]0E-01 cm @ 1/e points
Beam Divergence = [illegible].00E-4 radians

*Mode-locked to Pump Source @82 MHz
Pulsewidth less than 500 fs
Peak Power = 5.4 kW
Energy per pulse = 2.7 nJ

** Cavity-dumped Operation
Pulsewidth less than 1 ps
Peak Power = 45 kW
Energy per pulse = 45 nJ

4. Model GCR-3RA Pulsed Nd:YAG Laser/Regenerative Amplifier
Characteristics
GCR-3 - Not Seeded
Wavelength = 532 nm
Pulse Energy = 4.00E-01 J

Pulsewidth = 6.00E-09 s
PRF = 10 pulses/s
Beam Diameter = 7.00E-01 cm @ 1/e points
Beam Divergence = 5.00E-04 radians

Regenerative Amplifier - Seeded
Seed Pulse from Model 3800
Wavelength = 532 nm
Pulse Energy = 5.00E-02 J
Pulsewidth = 8.00E-11 s
PRF = 10 pulses/s
Beam Diameter = 7.00E-01 cm disk profile
Beam Divergence = 5.00E-04 radians

5. Model PDA-L3 Pulse Dye Amplifier
Characteristics
Wavelength = 585 nm
Pulse Energy = 1.00E-04 J
Pulsewidth = 1.00E-13 s FWHM
PRF = 10 pulses/s
Beam Diameter = 7.00E-01 cm disk profile
Beam Divergence = 5.00E-04 radians

REFERENCES CONSULTED

The following manuals were consulted for the writing of this paper:

ANTEL OPTRONICS

Model AR-S3 Picosecond Photodetector Manual

BBC

SE 420 Instruction Manual

HEWLETT PACKARD

X-Y Recorder 7000A/7001A Operating and Service Manual

INRAD

Model 5-14LD/1000 Autocorrelator Technical Manual

SPECTRADATA

SD85 Scan Controller Operation Manual

SPECTRA-PHYSICS

Model CPA-2 Fiber Prism Compressor for Chirped Pulse Amplification Instruction Manual
Model GCR-3RA Regenerative Amplifier Instruction Manual
Model 409 Scanning Autocorrelator Instruction Manual
Model 451, 452A, 453, and 454 Electronic Modules Service Manual
Model 3500 Ultrashort-pulse Dye Laser and Model 3290 Cavity Dumper
Model 3690 and 3695 Optical Pulse Compressor Instruction Manual
Model 3800 Continuous Wave Nd:YAG Laser System Instruction Manual
Quanta-Ray DCR-11 Pulsed Nd:YAG Laser Instruction Manual
Quanta-Ray GCR-3 and GCR-4 Pulsed Nd:YAG Laser Instruction Manual
Quanta-Ray PDA-1 Pulsed Dye Amplifier Instruction Manual

THERMO JARRELL ASH CORPORATION

82-410 Instruction Manual

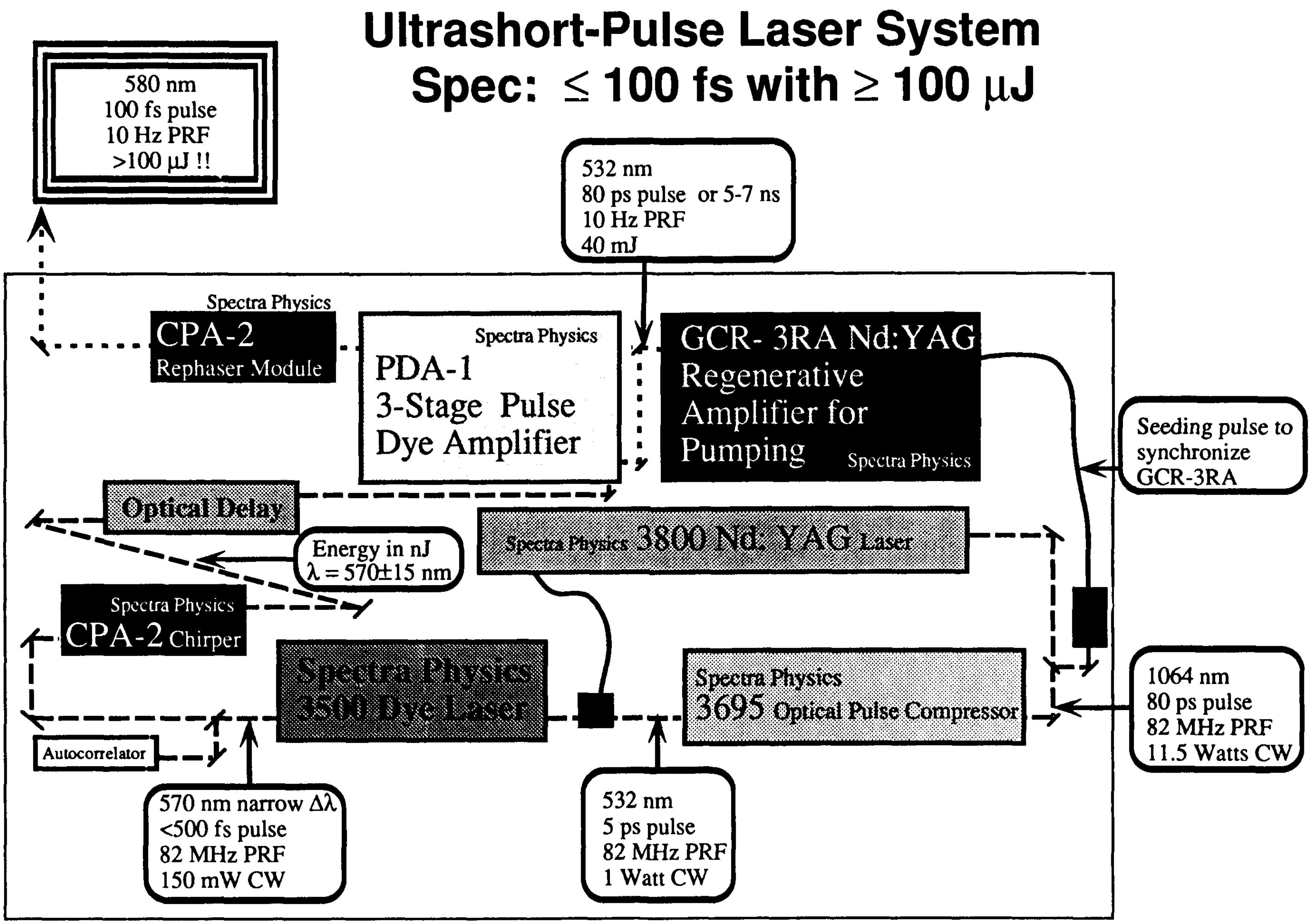

Figure 1. Block Diagram of Ultrashort-pulse System.

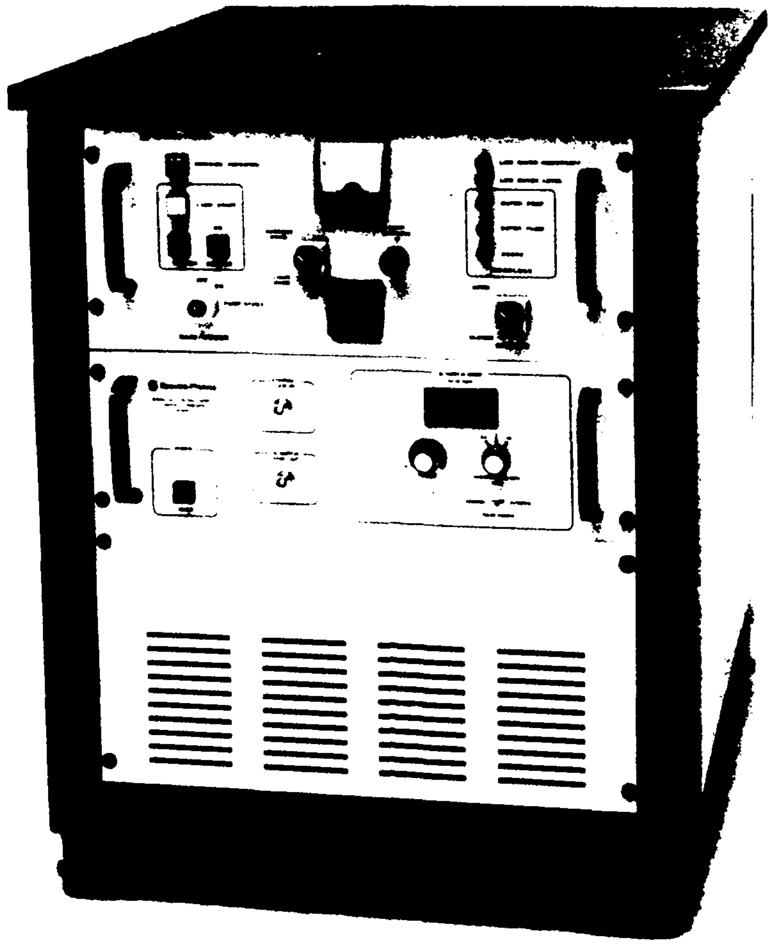

Figure 2. Model 3800 Laser System Power Supply.

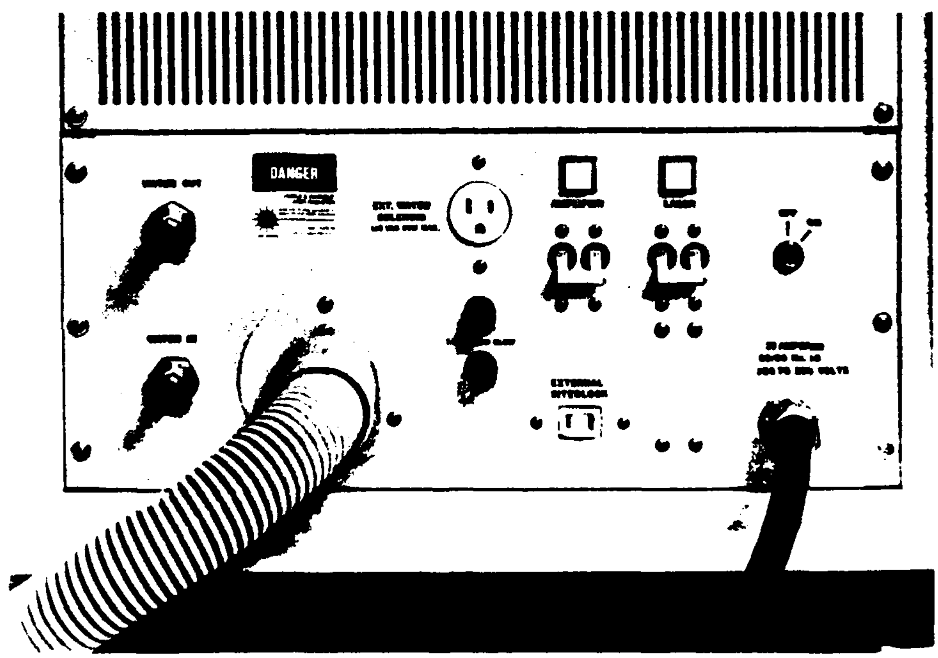

Figure 3. GCR-3RA Power Supply.

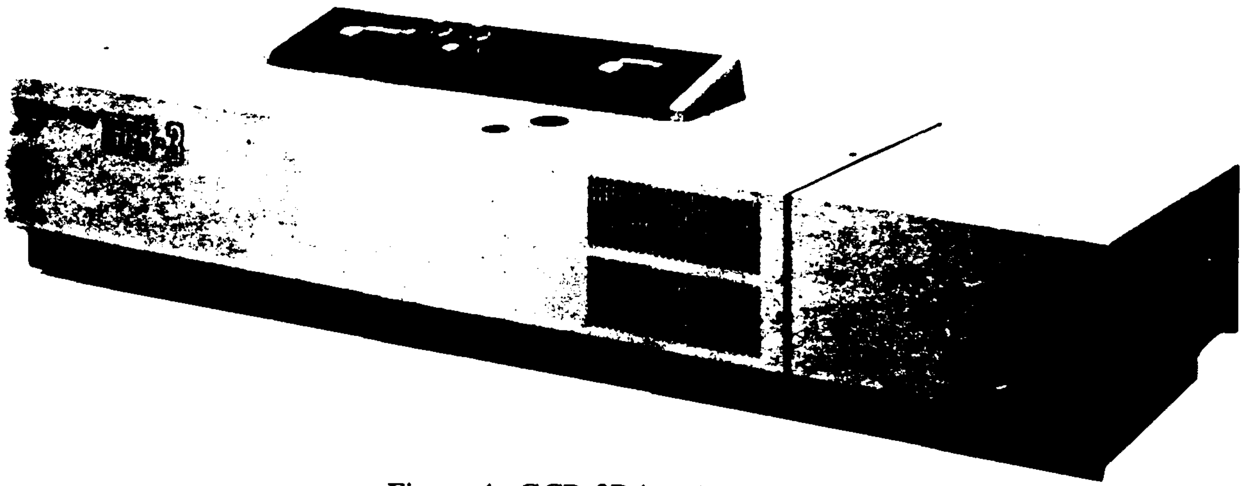

Figure 4. GCR-3RA Pulsed Nd:YAG Laser.

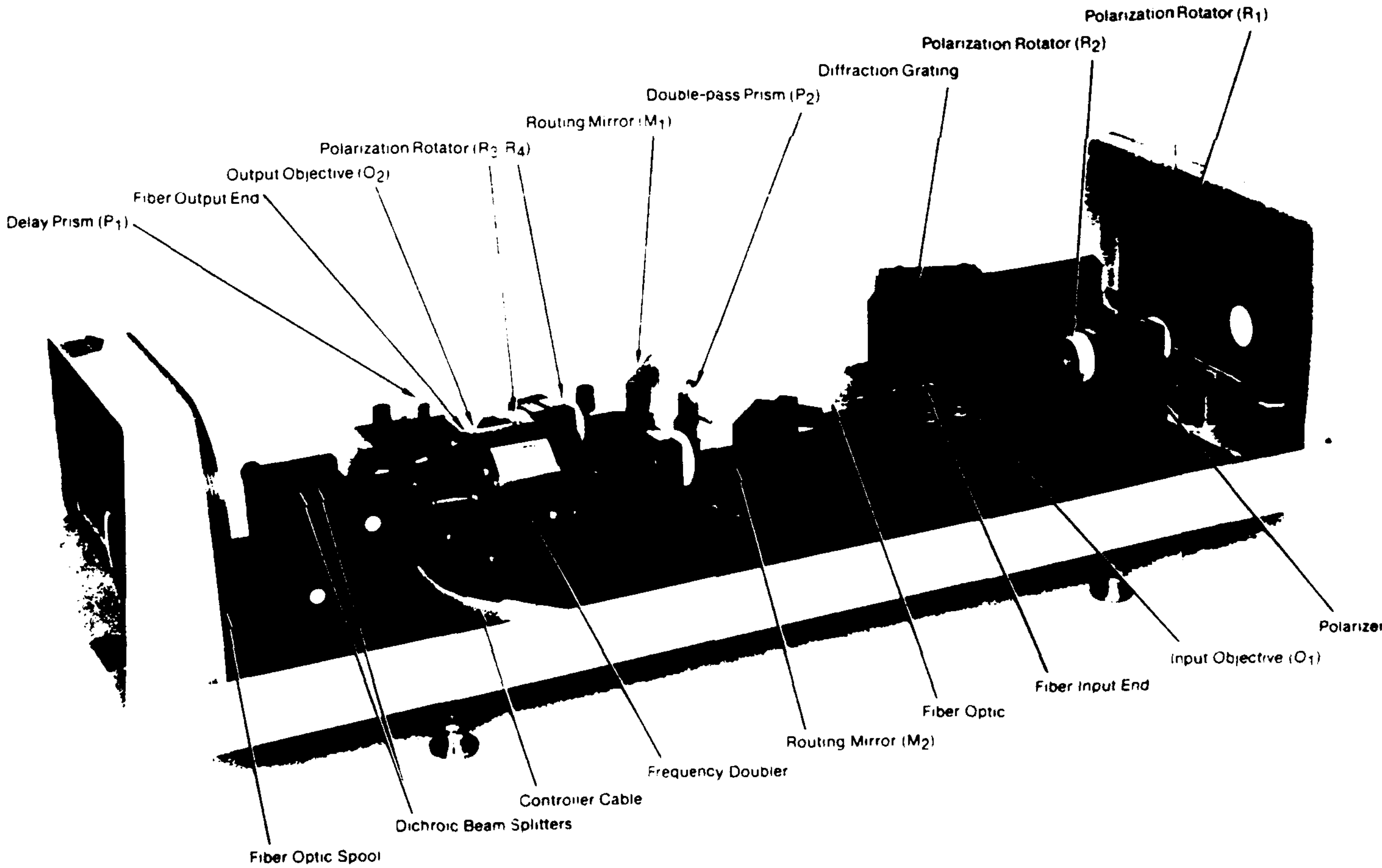

Figure 5. Internal View of Model 3695 Optical Pulse Compressor.

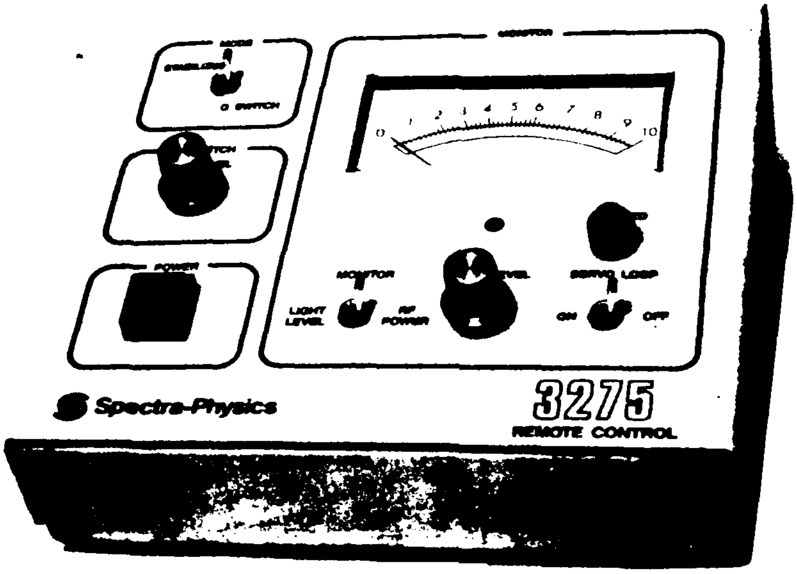

Figure 6. Model 3275 Remote Control.

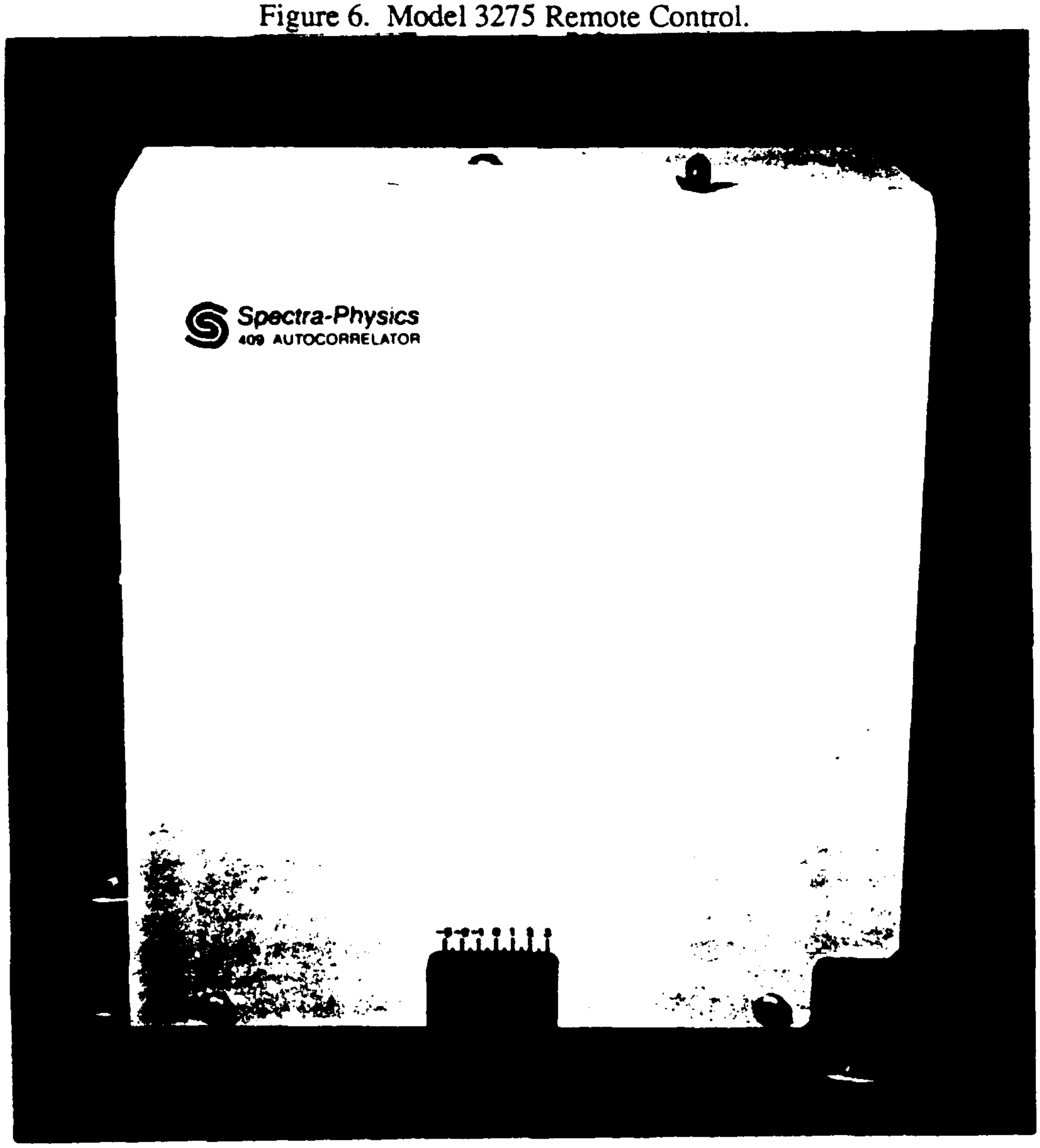

Figure 7. Model 409 Autocorrelator.

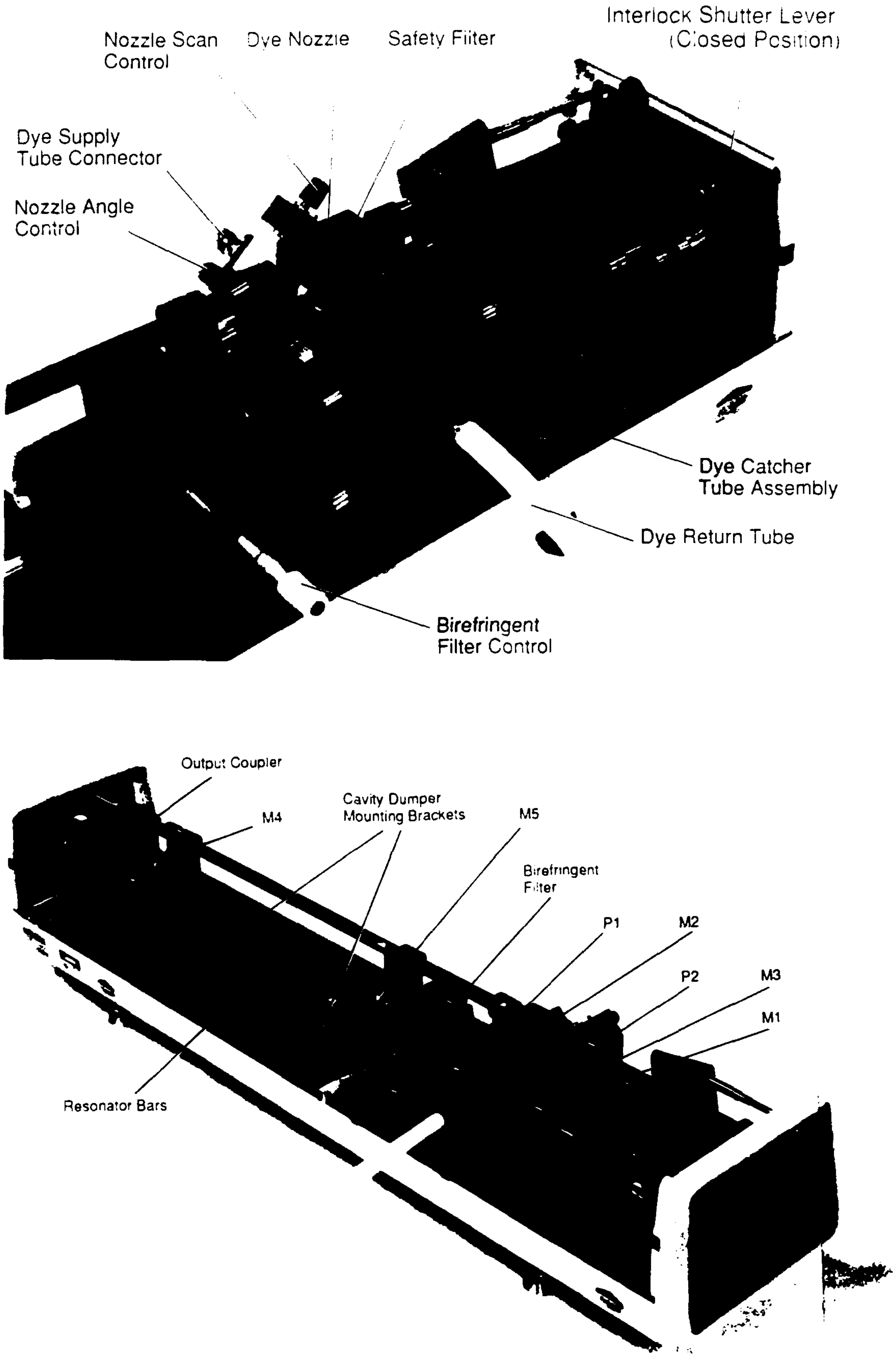

Figure 8. Internal View of Model 3500 Ultrashort-pulse Dye Laser.

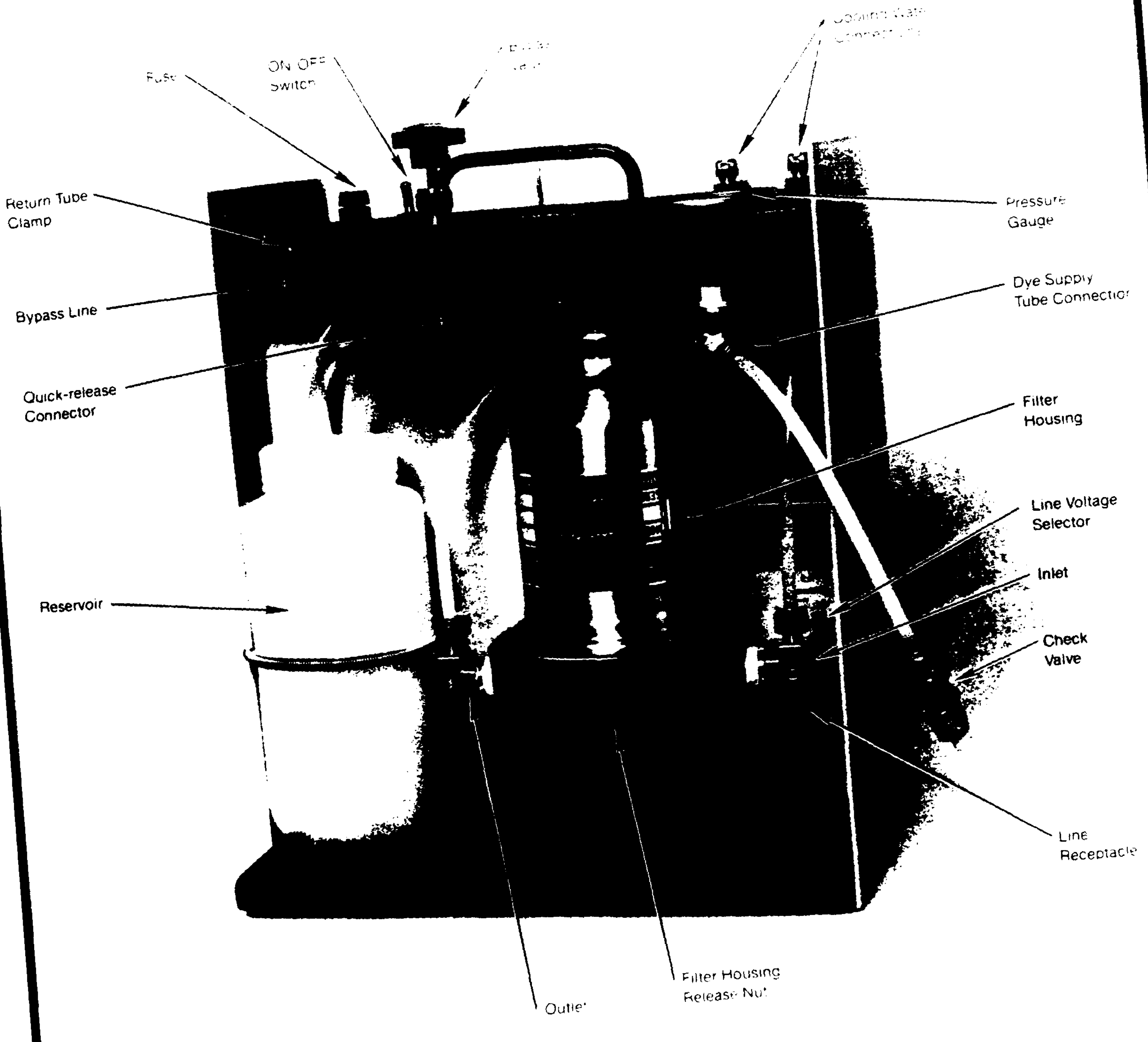

Figure 9. Model 3760 Dye Circulator.

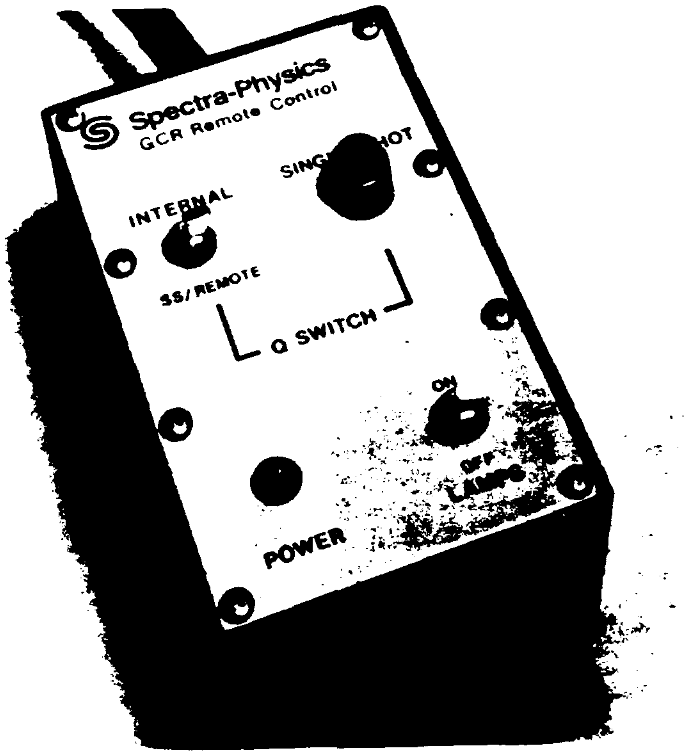

Figure 10. GCR-3RA Remote Control.

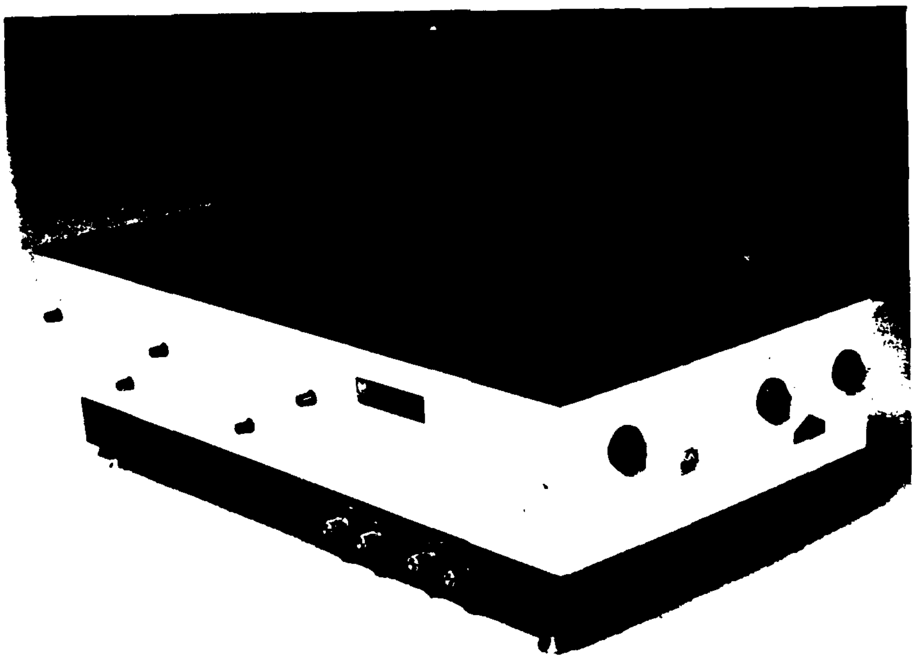
Figure 11. Model PDA-L3 Pulse Dye Amplifier.

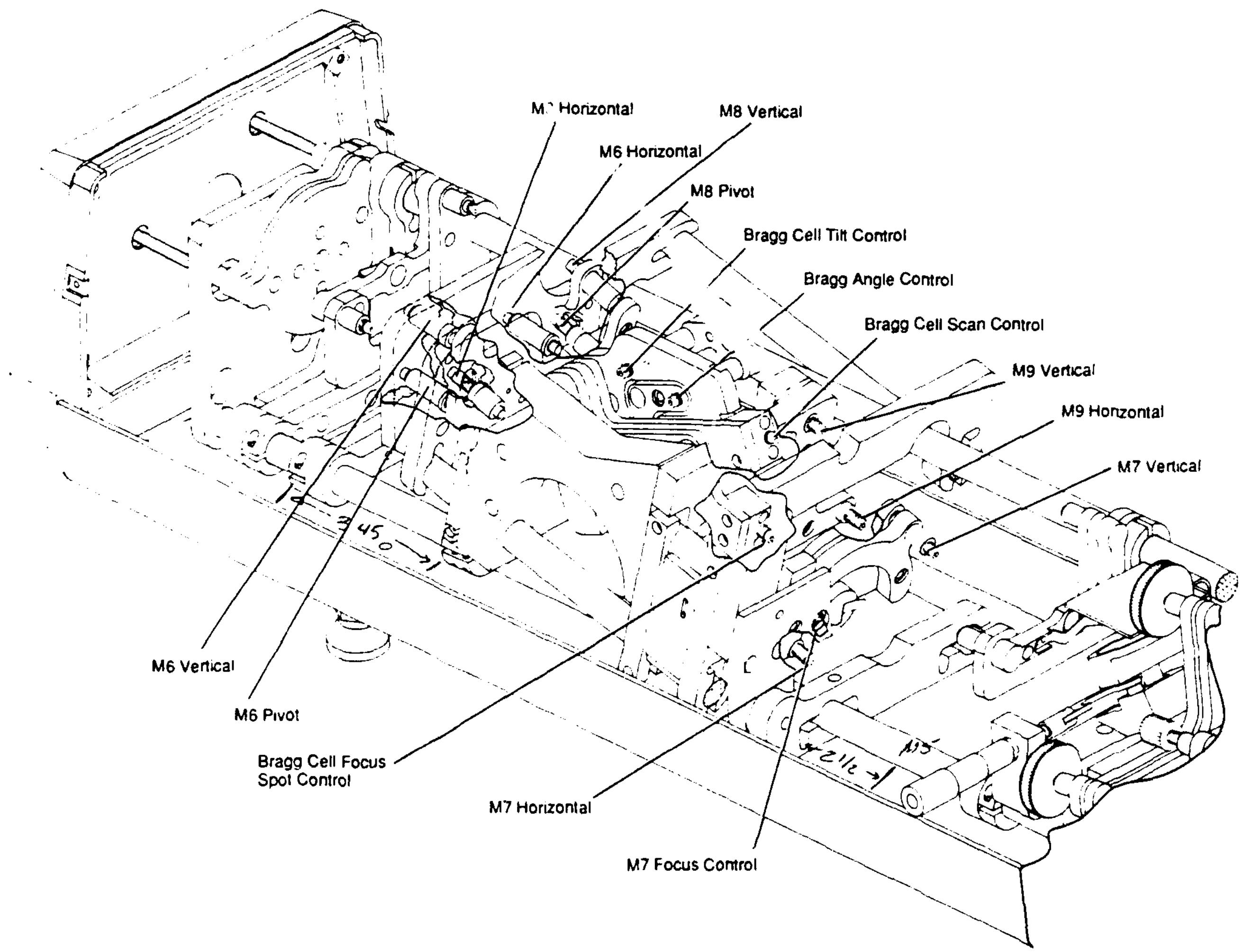

Figure 12. Model 3290 Cavity Dumper.

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